State Of Development – CIDI Engines

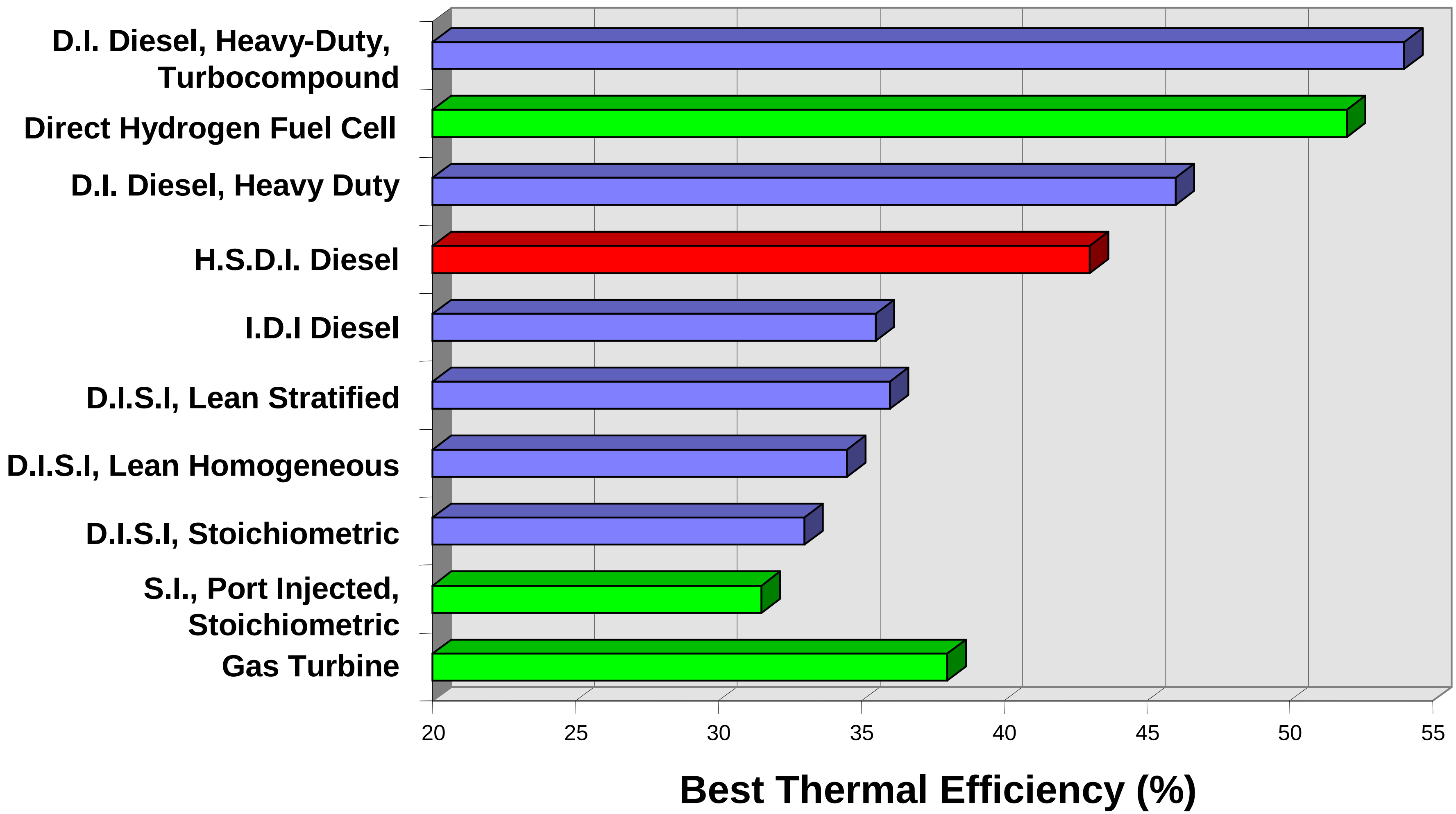
DOE Sensors Workshop

January 25-26, 2000

Rich Belaire

Ford Motor Company

Why Are We Interested In CIDI Engines ?



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Emerging HSDI Engine Features

Engine Feature	"Current" CIDI	Emerging CIDI	Advantage Over Current				
			NOx Emiss.	PM Emiss.	NVH	Power Density	Fuel Econ
Combustion System	Two Valve	Four Valve	●	●		●	●
Fuel Injection System	Rotary Pump	Common Rail	●	●	●	●	●
Aftertreatment	Oxidation Catalyst	Lean NOx Catalyst	●				
Boosting System	Fix-Geometry Turbocharger	Variable Geometry Turbo	●	●		●	●
Actuators	Pneumatic	Electric	●	●			
Base Structure	Cast Iron & Alum.	Aluminum				●	

Pre-Combustion → In-Cylinder Combustion → Post-Combustion

Fuel Reformulation
- Lower Sulfur
- Lower Aromatics

Oxygenates
- DME, DMM
- w/conv fuel

Fuel Additives
- Cetane Improvers

Dual Fuel

Design Parameters
- Cyl Head Layout
- Cam Events
- Intake Ports
- Compression ratio
- Piston Bowl

Fuel Inj Equip
- Common Rail
- Unit Injectors
- Rate Shaping
- Split Injection
- Piezo Systems

NOx Control
- Lean NOx Cats
- Non-Thermal Plasma

PM Control
- Oxy Catalysts
- PM Filters
- Thermal Oxidation
- Non-Thermal Plasma

NVH Refinement

- Strategy -

Turbocharging **EGR** **Sensors**

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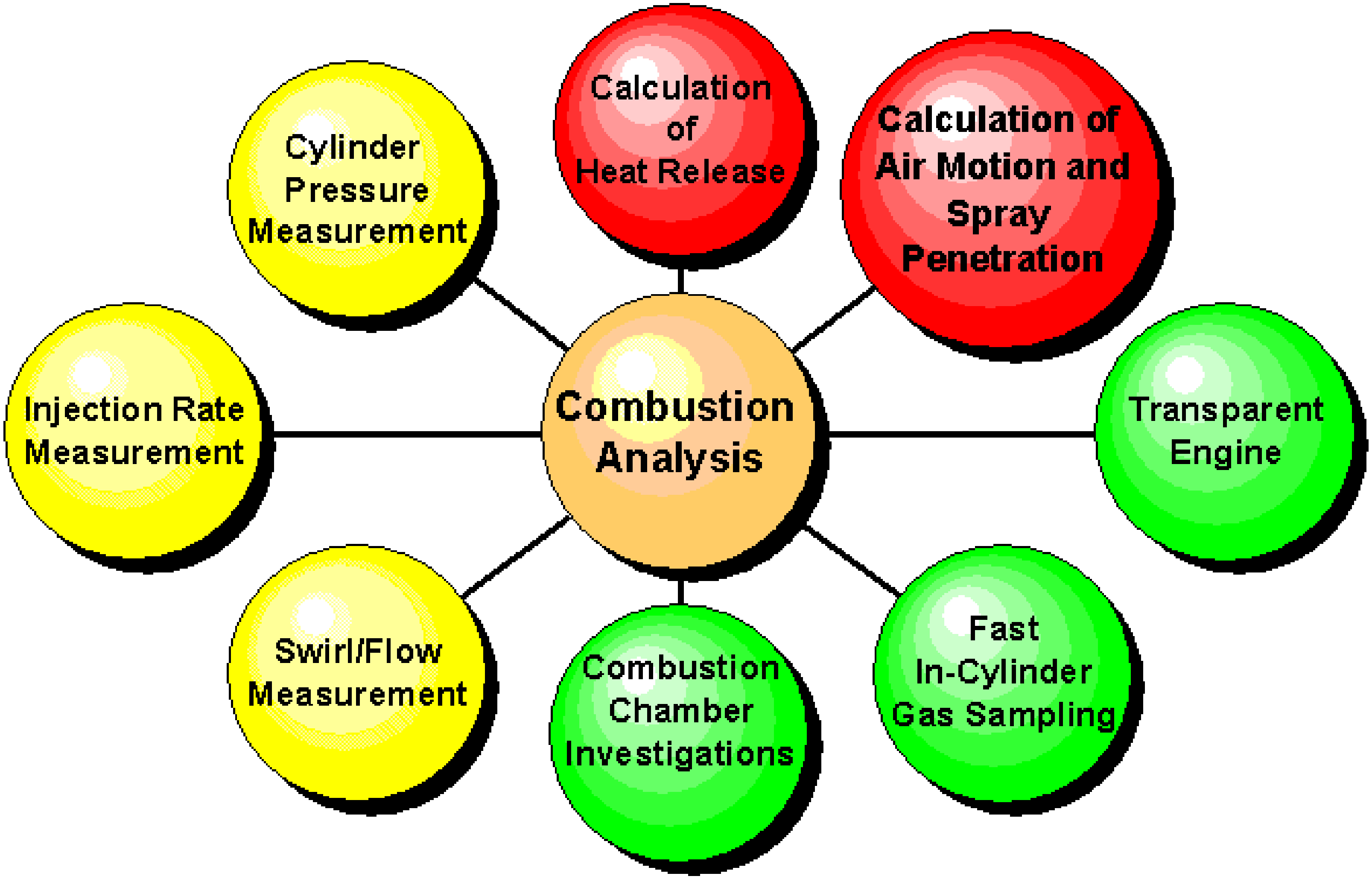
Tools Employed To Improve In-Cylinder Performance



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Light-Duty Diesel vs. Light-Duty Gasoline Vehicles

Environmental Benefits

- Up to 35% increase in fuel economy
- Greater than 15% decrease in CO_2 emissions
- Greater than 20% decrease in GHG emissions
- Very low CO and HC emissions

Environmental Concerns

- Order of magnitude greater PM emissions
- 2X increase in NO_X emissions

Trend Towards Higher-Speed Diesel Engines

Customer Benefits

- Improved Driveability
- Higher Power Output for a Given Peak BMEP
- Improved Fuel Economy, Lower Emissions

Enabling Technologies

- 4-Valves Per Cylinder
- Direct Injection
- High Pressure Fuel Injection Equipment
- Turbocharging, Intercooling
- Light Weight Materials, Balance Mechanisms

Example 1 : V8 BMW Diesel

Features :

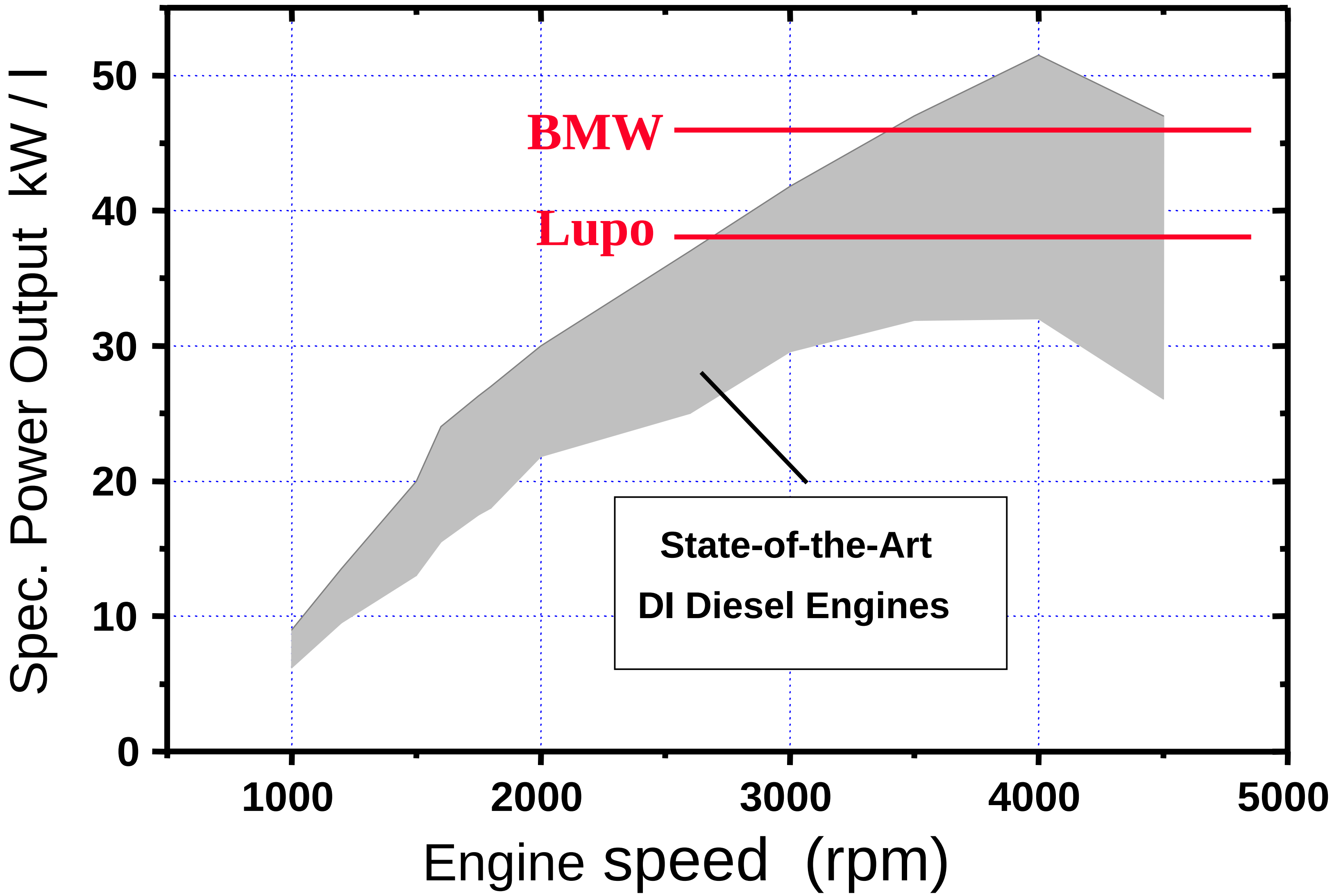
- 3.9 L Displacement
- 180 kW (245 bhp) @ 4000 RPM
- 560 Nm (413 ft-lb) @ 1800 RPM
- 4-Valves/cylinder, DOHC layout
- DI, High-pressure (1350 bar), dual common rail
- Dual VNT turbochargers, electronic control
- Dual air/air intercoolers
- Controlled, cooled EGR
- Iron block incorporating vermicular graphite

Example 2 : I3 VW Lupo Diesel

Features :

- 1.2 L Displacement
- 45 kW (61 bhp) @ 4000 RPM
- 140 Nm (103 ft-lb) @ 1800 RPM
- 2-Valves/cylinder, SOHC roller-rocker layout
- Single VNT turbocharger
- Cam-actuated DI unit injectors w/electronic control
- Single air/air intercooler
- Cooled EGR
- Aluminum cylinder head and block

CIDI Power Density (kW/l)



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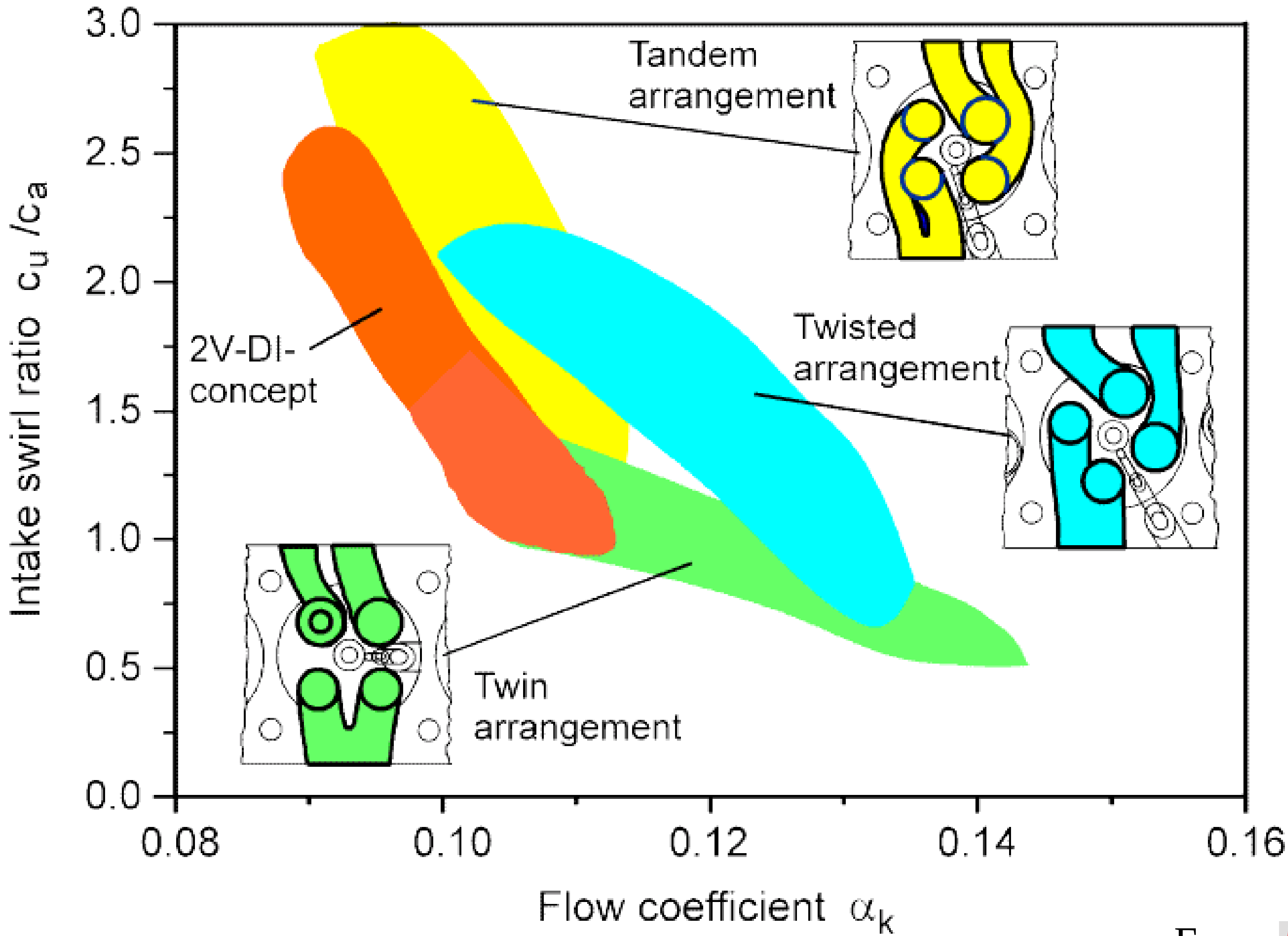
4-Valves Per Cylinder Architecture

- Allows Central Injector Location
  - ➔ Promotes Symmetric Fuel Distribution
- Higher Volumetric Efficiency
  - ➔ Supports High Excess Air Needs of Diesel
- More Flexibility in Trade-off Between Swirl and Airflow
  - ➔ Combustion System Optimization For Fuel, Emissions
- Reduces Valvetrain Mass
  - ➔ Possible NVH and Valvetrain Stability Improvements



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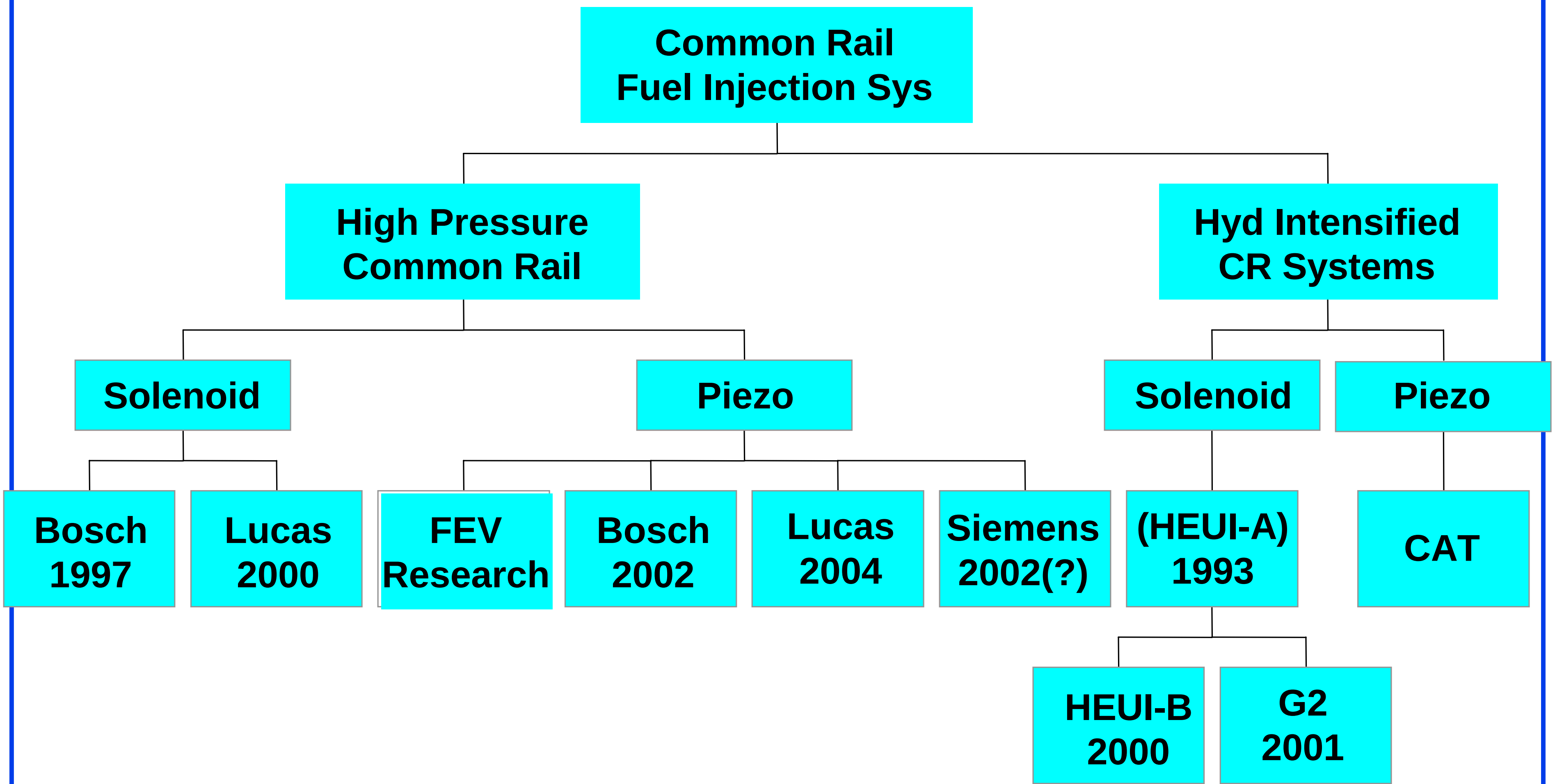
High Pressure Fuel Injection Equipment

- High Injection Pressure at Low Engine Speed
  - ➔ Small Fuel Quantities w/Excellent Atomization
- Higher Fuel Delivery Rates at Higher Engine Speed
  - ➔ Fuel-Derived Energy To Promote Diffusion Burning
- PM and NOx Emissions Control
  - ➔ Injection Rate Shaping Matched To Engine Speed/Load
- NVH Management
  - ➔ Rate Shaping To Control Rate Of Pressure Rise
- Can Support V6 and V8 Designs
  - ➔ Hardware and Software Speeds Increasing

Common Rail Fuel Injection Systems



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Fuel Injection Equipment (FIE)

Desirable Characteristics :

- High pressure over engine speed range
- Electronic control of pilot injection
  - Timing
  - Quantity of fuel injected
- Adjustable opening rate to control NO_X emissions
- Fast closing rate to minimize PM emissions
- Electronic control of multiple injection pulses
  - Combustion rate shaping
  - Providing exhaust HC for lean NO_X catalyst action
  - Split injections

High Pressure Fuel Injection Equipment

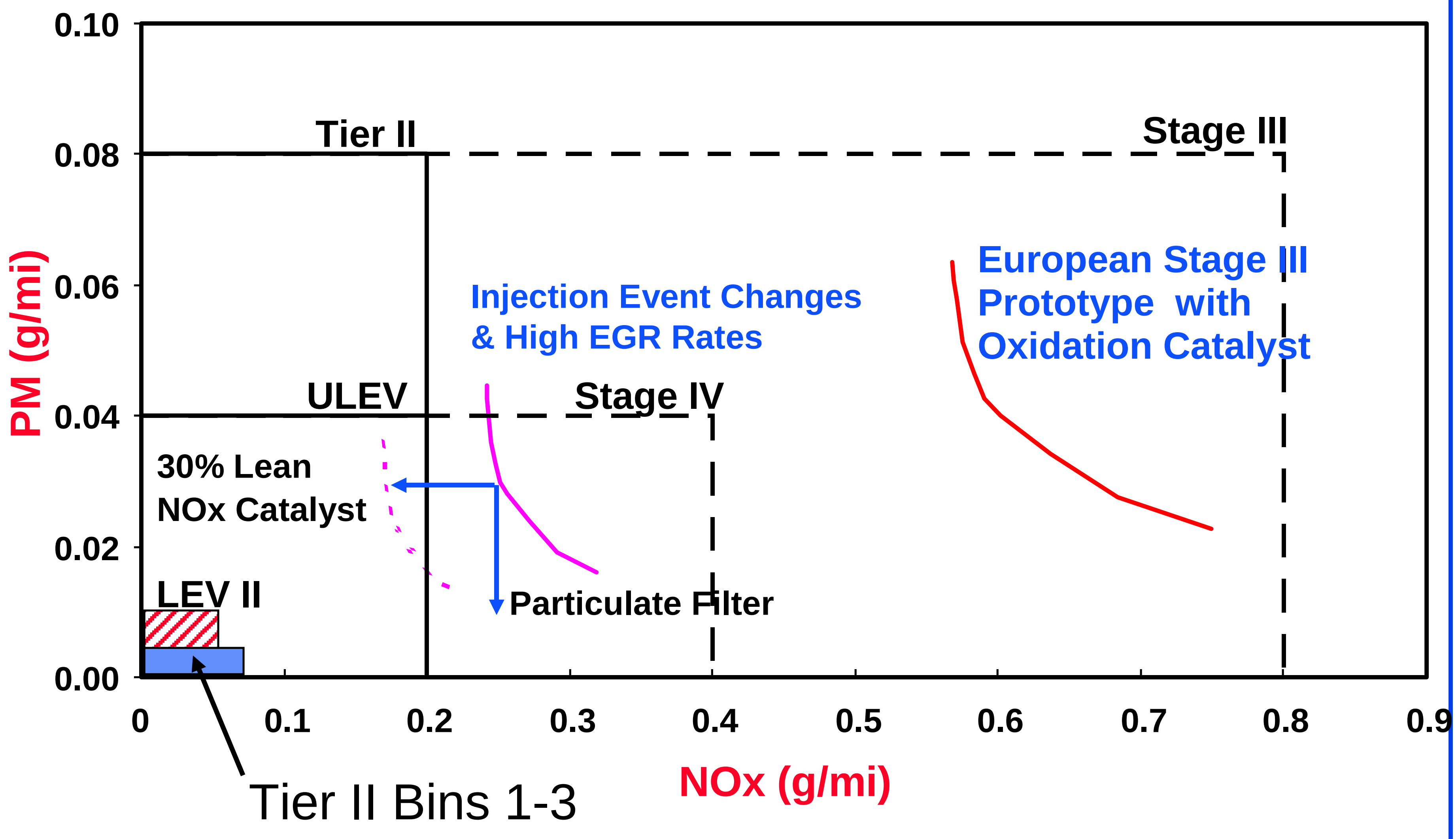
Achieving low engine-out emissions requires :

- Fuel injectors with small diameter holes
- High pressure at the nozzle tip

Current advanced FIE development focused on :

- Cam-driven, electronically controlled unit injectors
- High pressure common rail
- Intensifier fuel systems
- Piezoelectric actuated systems
- Injection rate control techniques
- Variable orifice nozzles

NOx - Particulate Trade-Off



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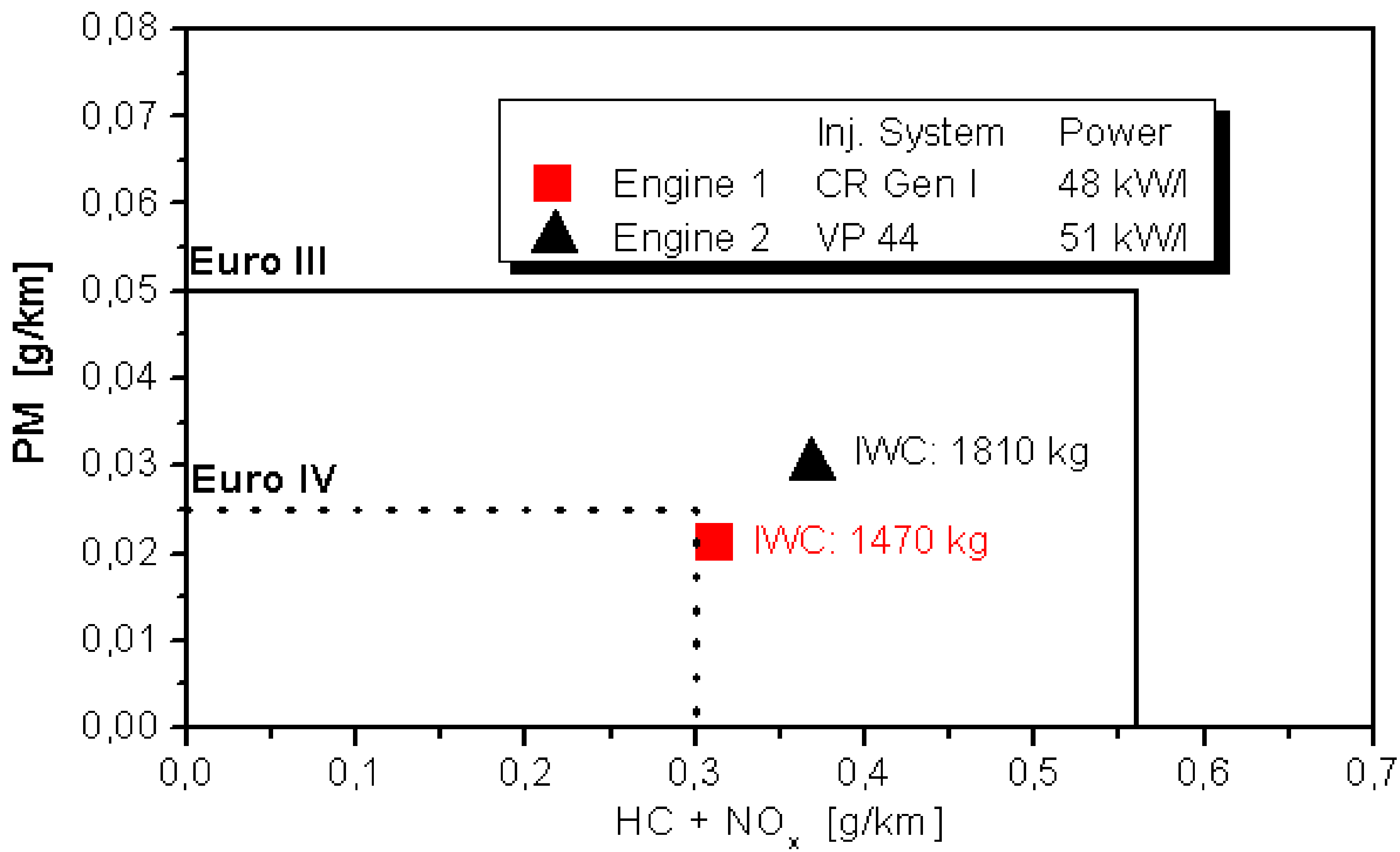

0,08
0,07
0,06
0,05
0,04
0,03
0,02
0,01
0,00
PM [g/km]
0,0
0,1
0,2
0,3
0,4
0,5
0,6
0,7
HC + NOx [g/km]
Euro III
Euro IV
Inj. System
Power
Engine 1
CR Gen I
48 kW/l
Engine 2
VP 44
51 kW/l
IWC: 1810 kg
IWC: 1470 kg

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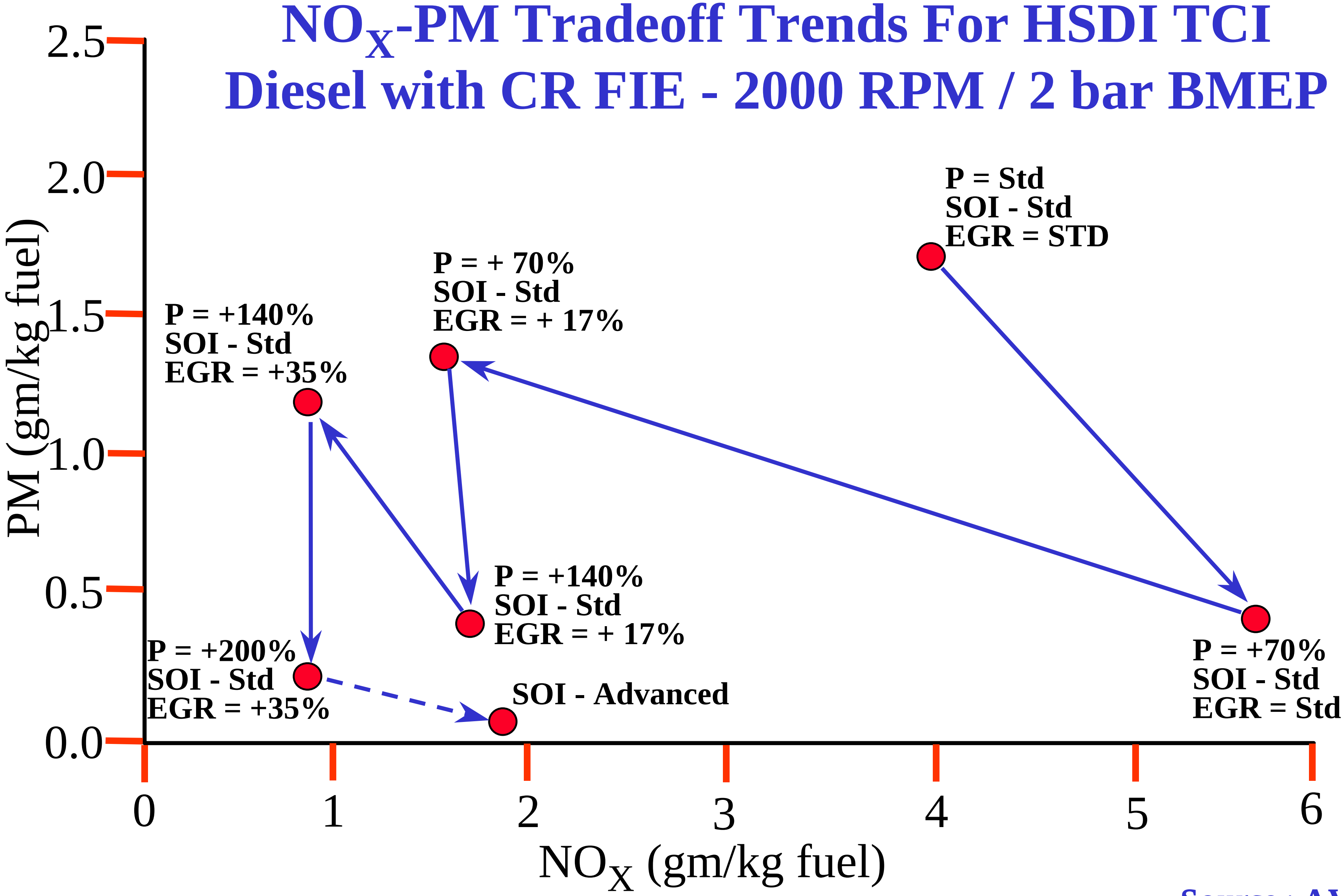
NO_X-PM Tradeoff Trends For HSDI TCI Diesel with CR FIE - 2000 RPM / 2 bar BMEP



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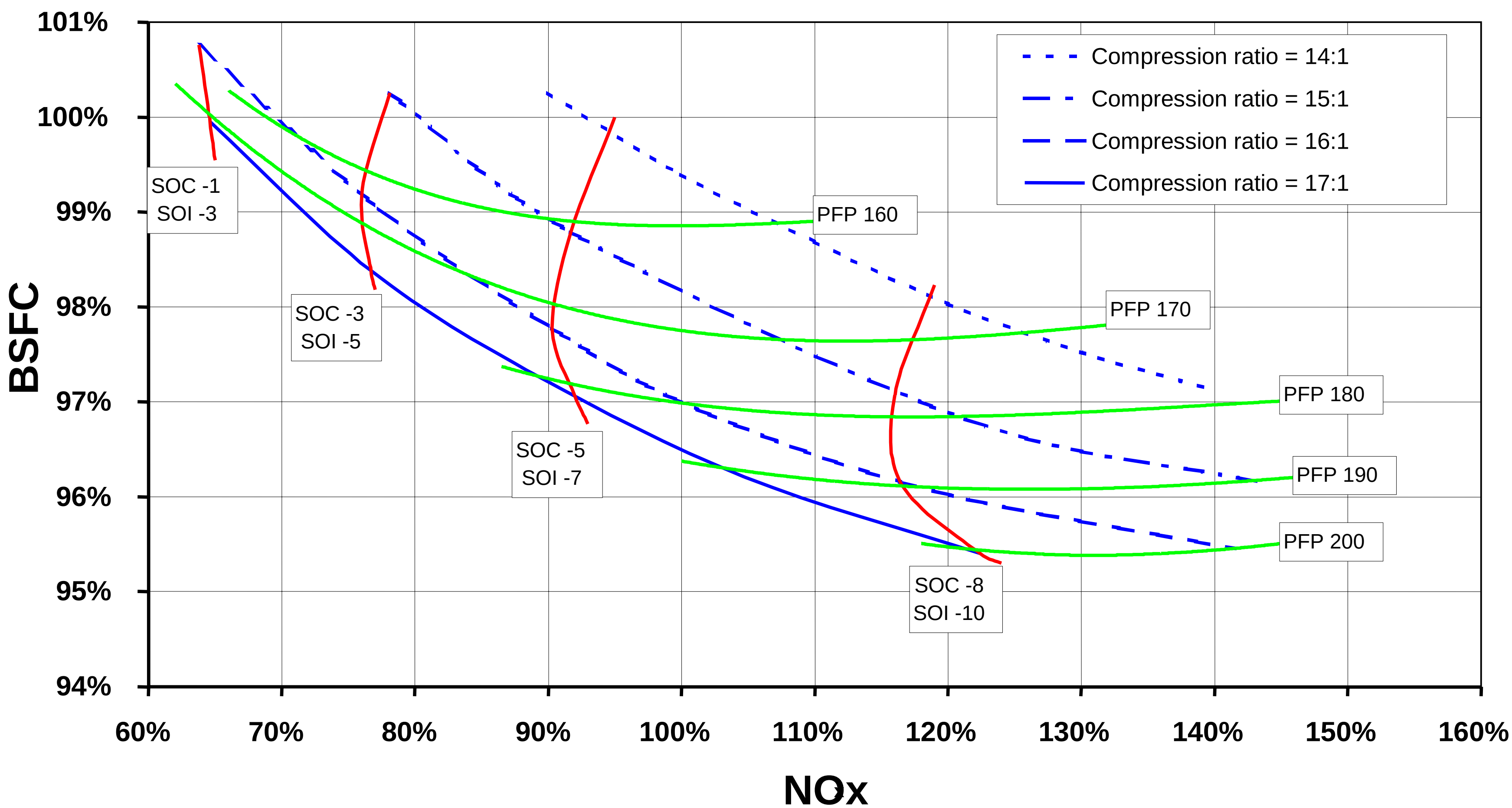
Source : AVL

Fuel Consumption Trade-Off



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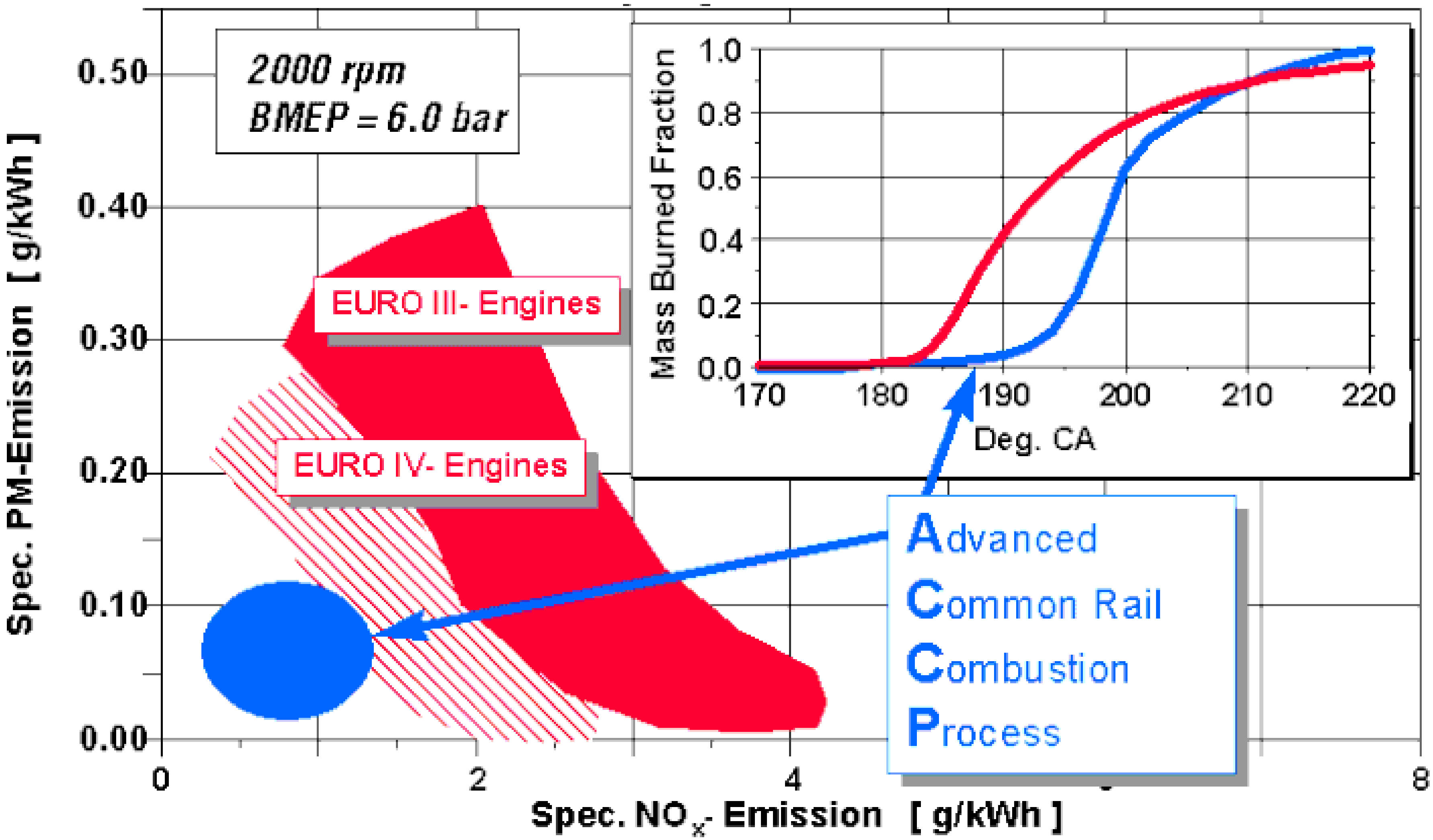

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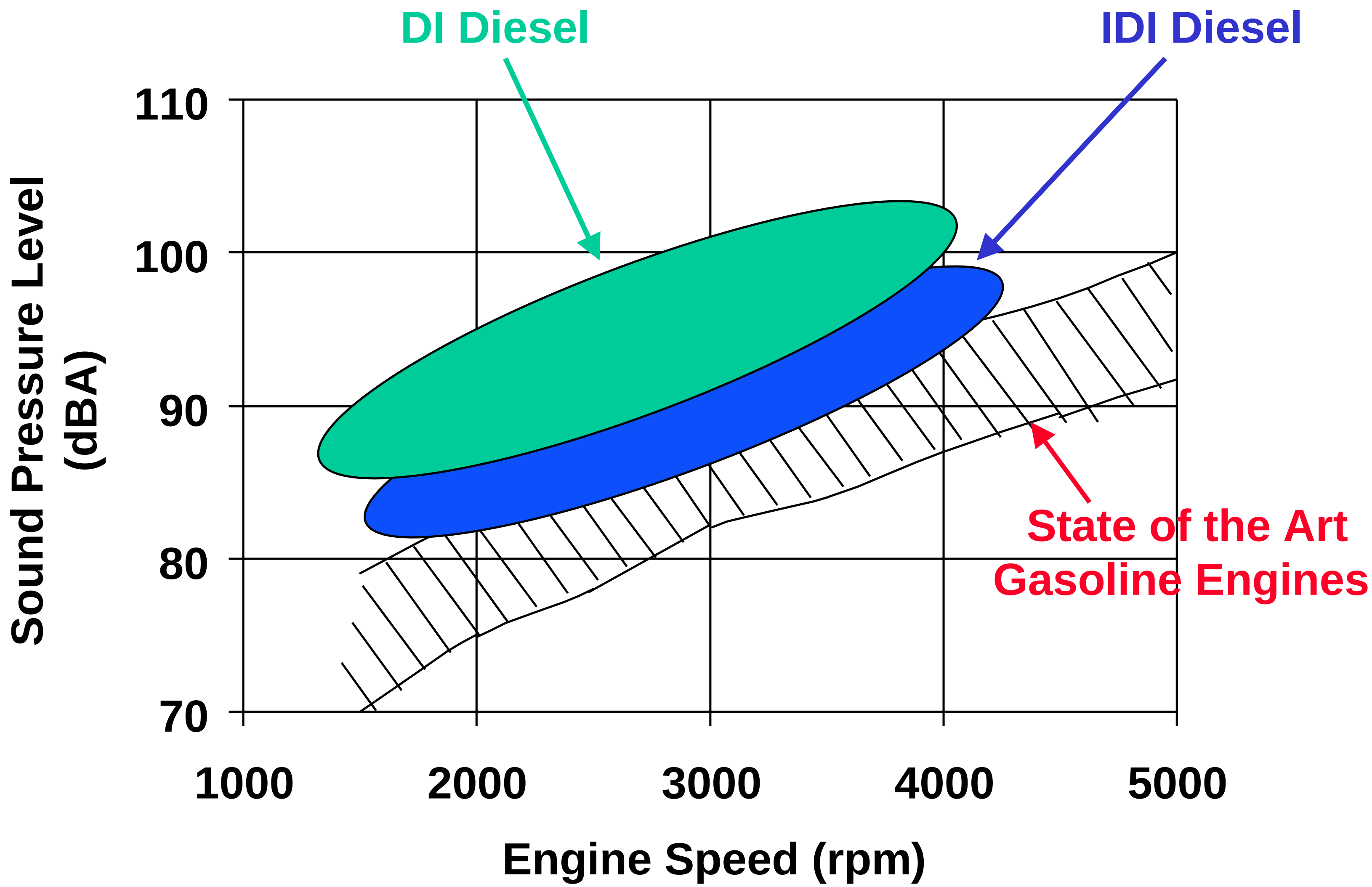
Broad NVH Comparisons



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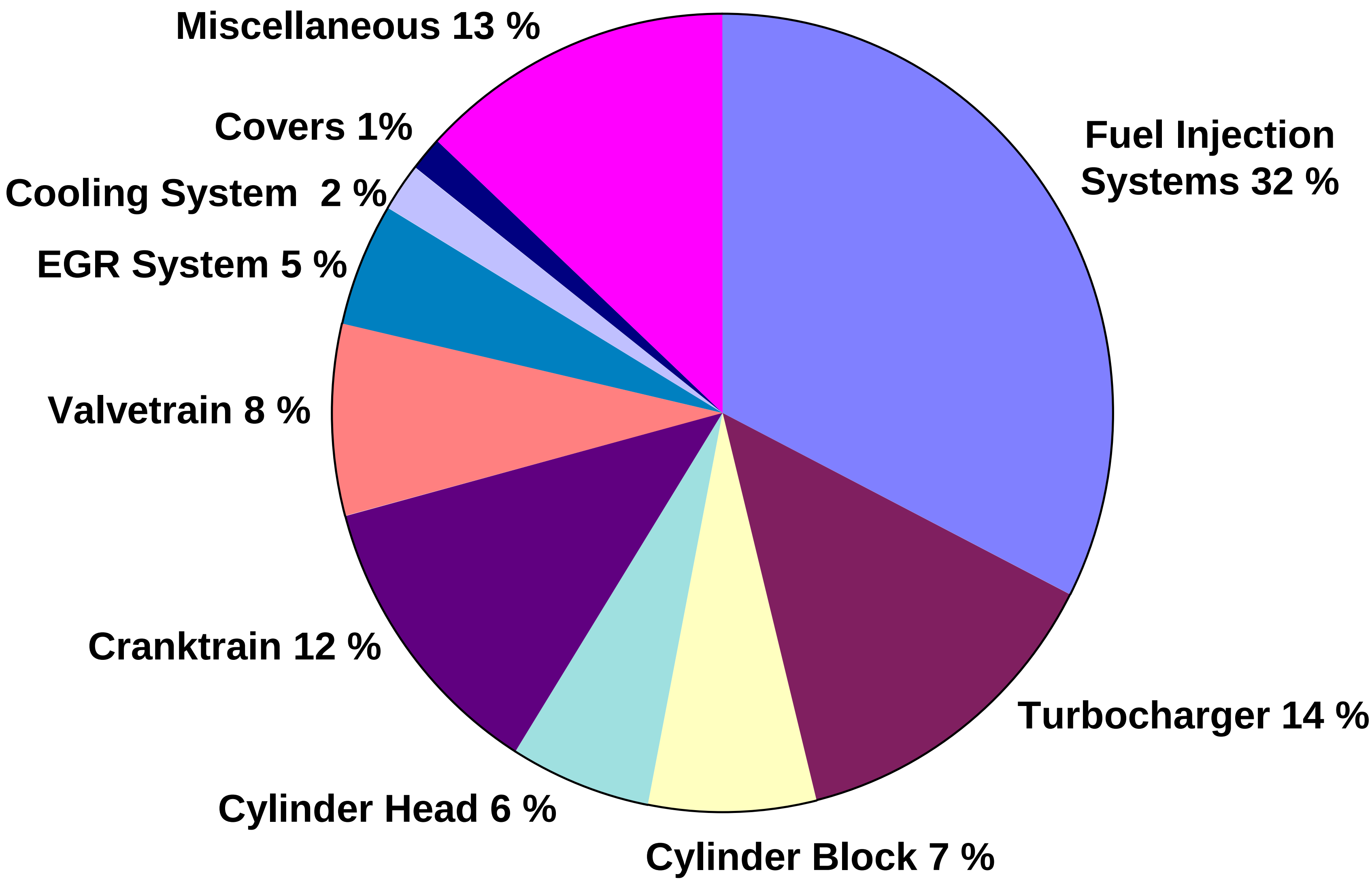
Typical Base Engine Cost Breakdown



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The Following Slides Were Not Used At The DOE Sensors Meeting On January 25/26, 2000 In San Francisco CA.

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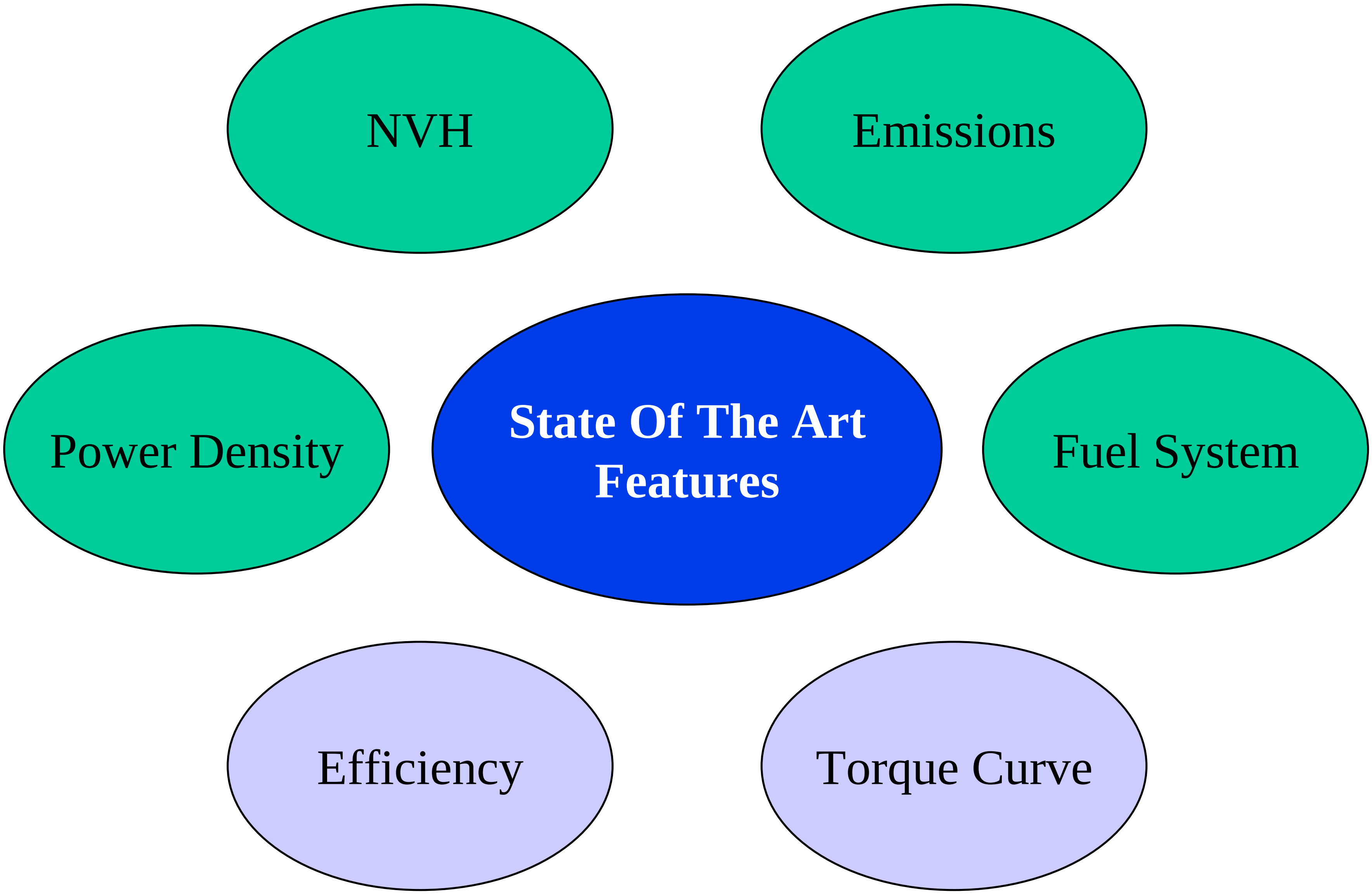
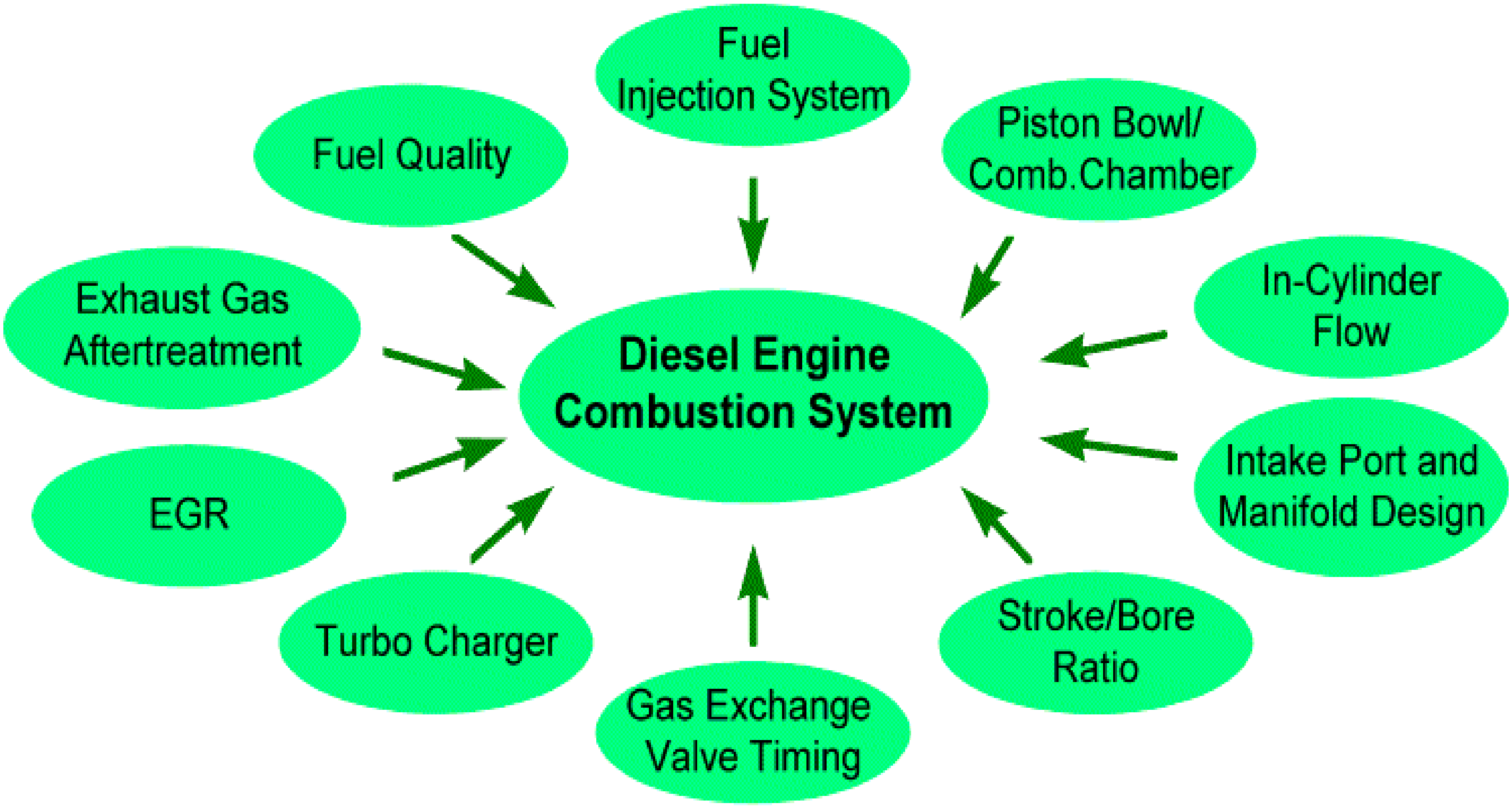

NVH
Emissions
Power Density
State Of The Art Features
Fuel System
Efficiency
Torque Curve



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Common Rail Fuel System Advantages Compared To Rotary Pump

- Precise Control of Injection Pressure
- Injection Timing Control
- Pilot Injection/Rate Shaping
- Post Injection for Active Catalyst
- Electronic Control Flexibility

High injection pressure improves fuel atomization and mixture preparation which :

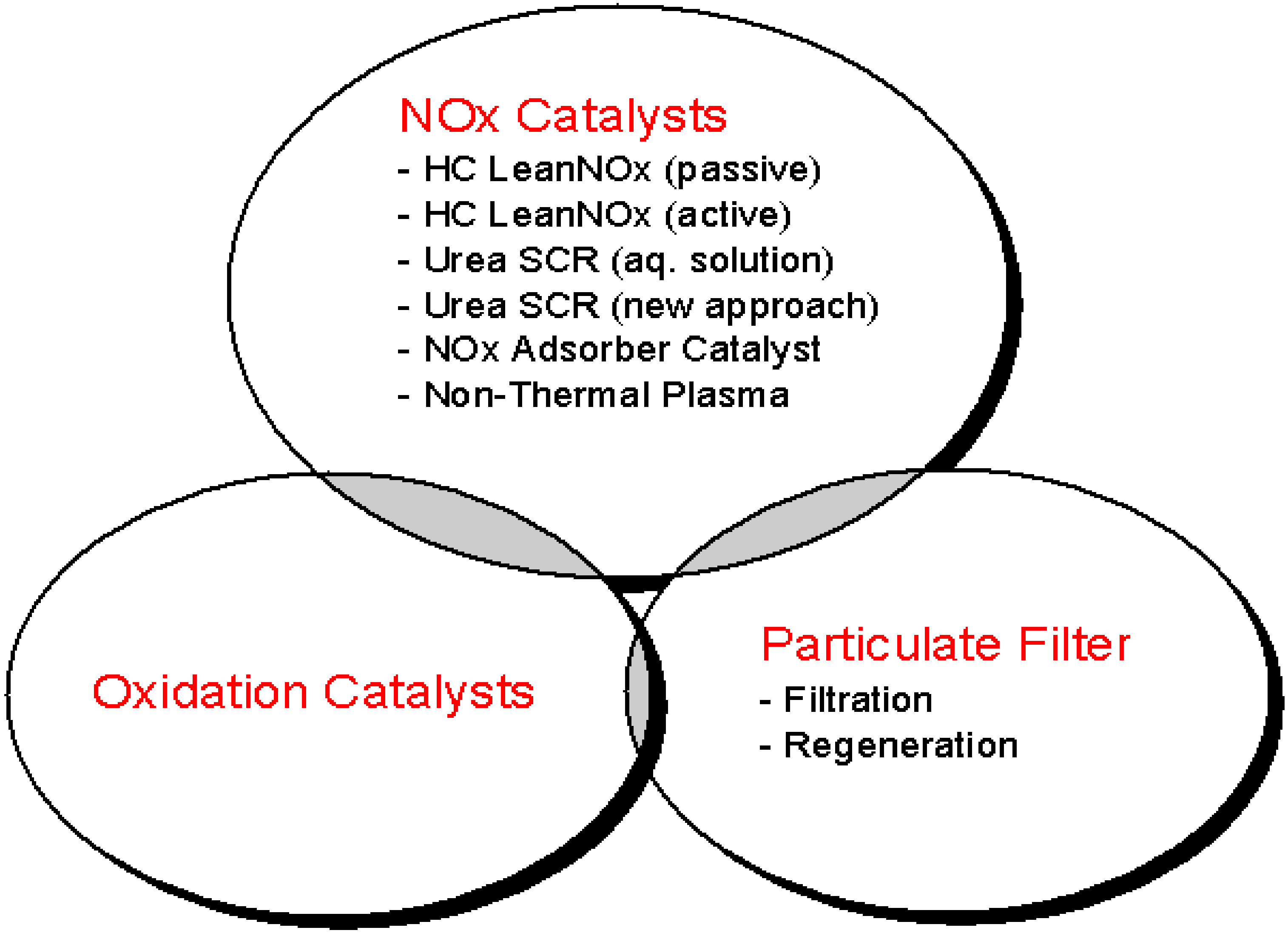
- Reduces particulate formation
- Improves smoke-limited power output and fuel consumption
- Increases tolerance to injection timing retard and increased levels of EGR, and reduces charge swirl requirement
- Enables engine operation at higher speeds

Turbocharging With Intercooling

- Improved Breathing Over Entire Speed Range
  - ➔ Supports High Excess Air Needs Of Diesel
- 2)
  - ➔ 2)
- 3)
  - ➔ 3)
- 4)
  - ➔ 4)

Light-Weight Materials

- Overall Lower Vehicle Weight
  - ➔ Improved Fuel Economy
- Reduced Penalty For Improving Engine Stiffness
  - ➔ Improved NVH Characteristics
- 3)
  - ➔ 3)
- 4)
  - ➔ 4)



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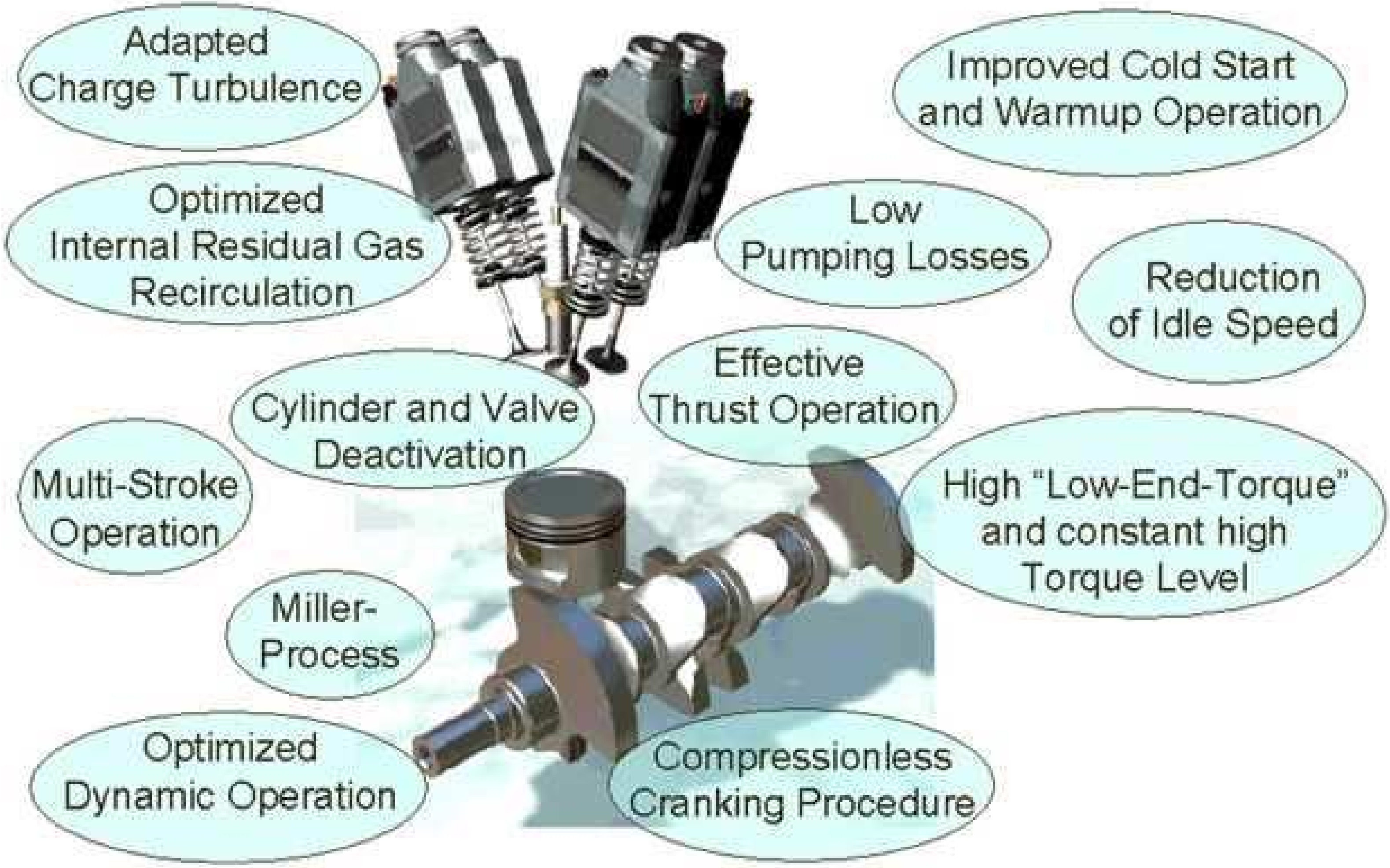
Injection Rate Shaping

- **Slow start of injection** - minimizes quantity of fuel injected during the ignition delay and hence reduces the rate of combustion pressure rise (noise) and peak temperature (NOx)

- **Rapid end of injection** - minimizes the quantity of poorly atomized fuel injected into the oxygen depleted combustion chamber at trailing edge of the injection pulse and maximizes residual charge energy hence reducing emissions of particulates and unburned HC and improving fuel consumption

Features Of Electro-Mechanical Valvetrain (EMV)



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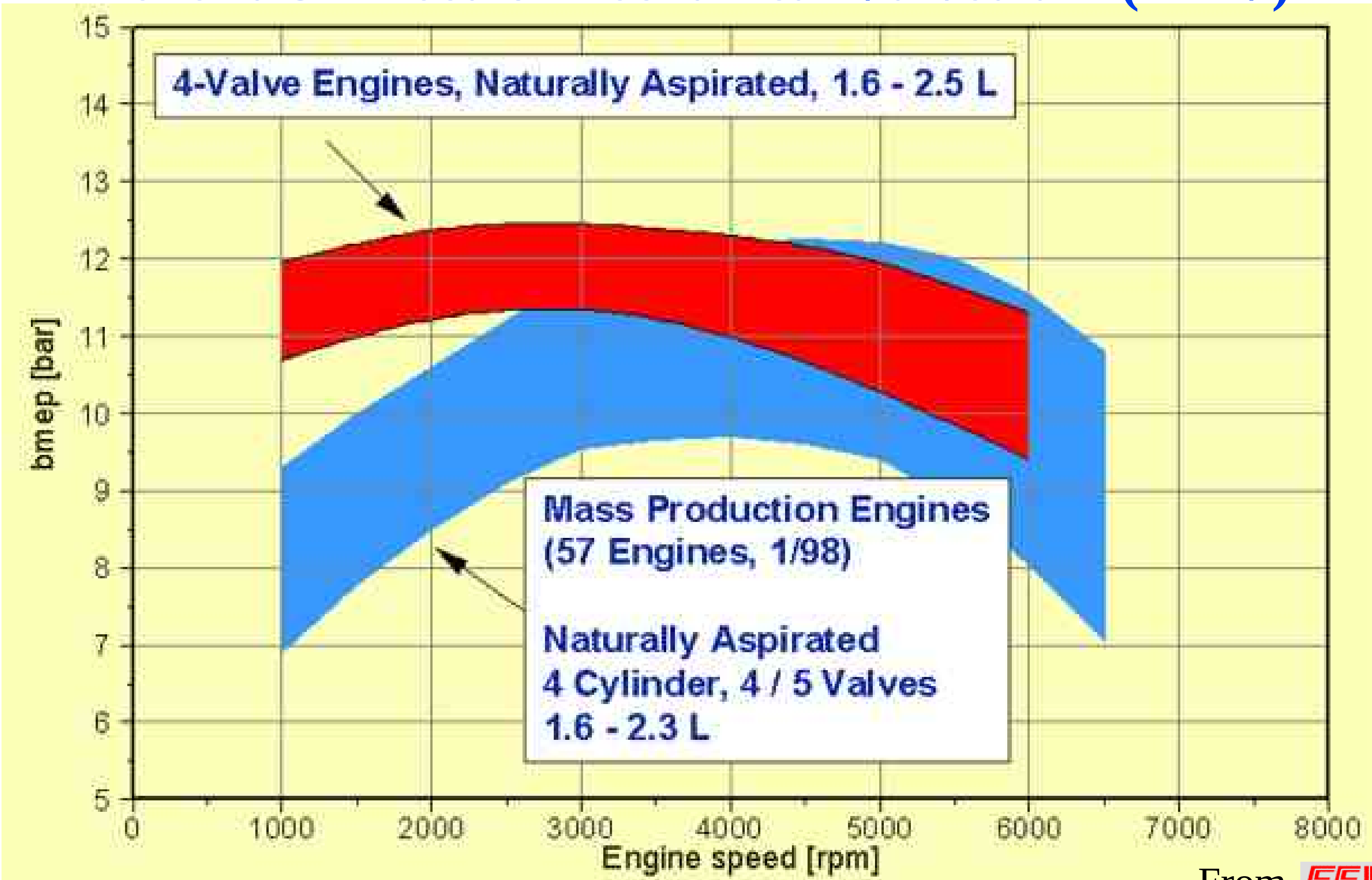
Benefit Of Electro-Mechanical Valvetrain (EMV)



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